Matched Field Tomographic Inversion for Geoacoustic Properties

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LONG TERM GOALS

The geoacoustic properties of the ocean bottom, including sound speed profiles, densities, attenuations and sediment layer depths, have a significant effect on sound propagation in shallow water. The long term goal of this work is to investigate tomographic inversion methods based on matched field processing of broadband data for estimating geoacoustic properties over an extended region of the ocean bottom.

OBJECTIVES

Matched field tomographic inversion provides a new approach for rapid, high resolution estimation of ocean bottom properties in to 3-D anisotropic environments, i.e. variability in depth, range and cross-range. The technique as envisaged by Tolstoy (1994) makes use of multiple vertical line arrays. An experiment to obtain acoustic field data for a multi-array system was successfully carried out using broad band and narrow band sound sources in the Haro Strait Primer Experiment in June 1996. Another multiple array experiment with broadband sources was carried out in the Santa Barbara Channel (SBCX) in April 1998. The objectives of the present study are to develop approaches for using multiple array data to invert geoacoustic parameters in range-dependent environments, and to apply the methods to the Haro Strait and SBCX data.

APPROACH

An extensive data set was collected in the Haro Strait Primer experiment, using light bulbs and continuous wave projectors as sound sources and three vertical arrays separated by about 1 km. (Chapman et al., 1997). Two approaches were tested for using the information from multiple sources and arrays. The first was the development of vertical slice tomography using data from two vertical arrays. This inversion is appropriate for the broadband signals and is based on ray theory to calculate replica acoustic fields for a novel, pair-wise matched field processor that is insensitive to mismatch in the sound source waveform. A two-stage inversion scheme was investigated that first estimates bounds for the sea floor geoacoustic parameters using a partial set of ray paths, and then estimates all the geoacoustic parameters using all ray paths. For the CW tone data, a different approach was taken to use multi-frequency information received at a single array from several positions of the towed source. The method introduced a simple parameterization of the array shape to determine hydrophone positions, since the strong currents in Haro Strait caused significant deviation from a linear array model. The inversion used a Parabolic Equation (PE) code to calculate the acoustic fields for the range-dependent environment.

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14. ABSTRACT
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The experimental configuration of the vertical arrays in SBCX was a close, pentagon shaped cluster, with each array separated by 200 m. For this configuration, a linearized inversion was applied first to localize the arrays and subsequently estimate sediment velocity and density by inversion of broadband reflection coefficient data derived from the light bulb sound signals received at all the arrays.

WORK COMPLETED

Simulations were completed to investigate the performance of vertical slice tomography to invert the geoacoustic parameters for a range-dependent environment that modeled the Haro Strait site (Fig 1). The inversion was based on a ray propagation model, and used the pairwise matched field processor for broadband data. This work was carried out by V. Corre in her PhD thesis project (Corre, 2001)

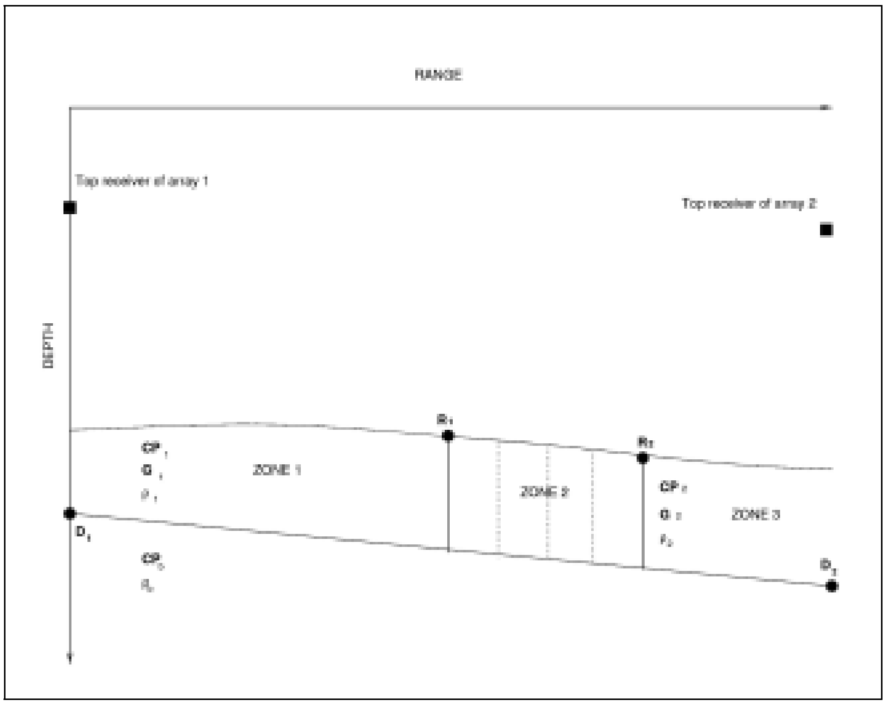

Figure 1. Vertical slice configuration and geacoustic model of the Haro Strait waveguide.

Multitone CW data obtained at the southwest array deployed in Haro Strait were processed in a statistical appraisal algorithm developed by Dr. J. Viechnicki to estimate the array geometry.
The SBCX light bulb data were processed in a simple, linearized travel time inversion to localize the array positions. Reflection coefficients were determined from the broadband light bulb sound sources that were deployed within 1 km of the arrays. These data were inverted to estimate sediment geoacoustic parameters in the vicinity of the arrays.

RESULTS

Initial analysis of the data for estimation of local geoacoustic properties has been reported previously (Chapman et al., 2000). Vertical slice tomography was tested in simulations for a planar two vertical array scenario (Fig. 1). Synthetic data for this study consisted of pressure fields that were generated by

three broadband sources in the plane of the arrays. The environment was a 3-layer waveguide (water, sediment and subbottom) that was range dependent, consisting of three zones, two homogeneous sloping bottom segments separated by a transition zone. The inversion estimated the density, and the p-wave velocities and gradients in each homogeneous layer, the range to the transition zone, and the thickness of the sediment layer. The study was carried out for signal to noise ratios (SNR) of 10 and 15 dB, and for mismatch in the array geometry. The simulations showed that a two stage inversion process was computationally efficient and effective in providing accurate estimates of all the model parameters (Corre, 2001; Corre and Chapman, 2001). Application to the Haro Strait data involved a preliminary inversion to establish the experimental geometry (Corre and Chapman, 1999). The geoacoustic model parameters estimated by the vertical slice technique were in good agreement with estimates of the local environment at each array that were made using conventional single-array geometries (Chapman et al., 2000; Pignot and Chapman, 2001; Corre, 2001).

The analysis of the CW data demonstrated the importance of using a realistic parameterization for the shape of a bottom moored vertical array to account for the significant distortions in array shape caused by the strong currents that can occur in shallow water. The shape was modeled as a catenary described by the ratio of buoyancy and current drag parameters. The array geometry, shape and range to the source, was accurately estimated in a bayesian inversion algorithm. Performance of the inversion was sensitive to the method for modeling the range dependent shallow water environment. Best results were obtained using the known bathymetry between the source and the array. Range estimation accuracy was severely degraded for a flat bottom-average depth model of the channel (Viechnicki and Chapman, 2000).

Inversion of the SBCX broadband light bulb data provided an independent estimate of the location of the five vertical arrays that were deployed in the experiment. Our estimated positions are within estimation error of the positions estimated previously by the SBCX researchers from data obtained in an array element localization experiment. The reflection coefficient inversion provided estimates of the sea floor geoacoustic parameters in the vicinity of the SBCX arrays. The results indicate a gradual increase of sediment velocity with increasing water depth (Chapman and Hudson, 2000). Both sets of estimates are posted on the SBCX website.

IMPACT/APPLICATIONS

The Haro Strait experiment was the first opportunity to investigate the concept of geoacoustic matched field tomography. To date, several new results have been obtained in developing an approach for inverting the multi-array data. The freeze bath inversion method provides a meaningful error measure for the inverse problem, as well as the estimate of the optimum value (Chapman and Jaschke, 2001). This approach holds interest for seismic as well as acoustic inversion. The pairwise matched field processor has been shown to provide improved performance compared to the conventional Bartlett-family processors. The improvement is due to its reduced sensitivity to the unknown source waveform (Corre, 2001). The vertical slice tomographic inversion method provides an efficient means for estimating geoacoustic properties over an area. Its improved performance is due to the increased amount of information (from the multiple arrays) in the cost function.

The shape of bottom moored vertical arrays deployed in shallow water is strongly affected by currents in the water. Our simple parameterization provides a realistic description of the array shape for use in matched field inversion applications.

The straightforward linearized inversion of the light bulb data proved to be an effective and simple method to estimate array geometry of the SBCX arrays. Our estimates were in close agreement with those by the SBCX group. This result is important since our estimate was based on data obtained at the beginning of the experiment. The close agreement with the SBCX position confirmed the results that were obtained from the localization experiment carried out at the end of the sea trial.

TRANSITIONS

The broadband light bulb data from the Haro Strait experiment were used by collaborators from MIT in an ocean acoustic inversion of the sound speed profile over the are enclosed by the arrays (Elisseeff et al, 1999), and by researchers at the Defence Research Establishment Atlantic in an investigation of the source level of light bulb implosions (Heard et al, 1997). The Haro Strait data have been provided to three other investigators: Dr. Alex Tolstoy has used the Haro Strait concept in her simulation work, and intends to use some of the broadband data in her investigations of geoacoustic inverse methods that have been funded by ONR (Tolstoy, 2000); Dr. Eliza Michalopoulou has received samples of the light bulb signals and used them in her research; Dr. H. Schmidt used the high resolution bathymetry data in the geoacoustic tomography experiment for evaluation of an inversion method based on the high frequency tomography source data (Egnor et al, 2000).

RELATED PROJECTS

This work on geoacoustic inversion is related to several other projects currently funded by ONR; information has been exchanged in discussions with investigators in each project to describe the results of the Haro Strait experiment. These projects include: the Yellow Sea experiment (Peter Dahl, APL, Washington); the SHELFBREAK Primer experiment (Jim Lynch, WHOI and Kevin Smith, NPS); and the geoacoustic inversion investigations of Mediterranean Sea data by Alex Tolstoy and Peter Gerstoft. Geoacoustic inversion using light bulb sound sources was used in the Santa Barbara Channel experiment in April 1998.

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